OBSERVATIONS USEFUL FOR INCREASE OF HYDROCARBON FIELDS EXPLOITATION PERIOD WITHIN A CROATIAN PART OF THE PANNONIAN BASIN

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ABSTRACT

Approximately $110x10^6$ m^3 of oil ($100x10^6$ tons) had been recovered from 38 fields in the Croatian part of the Pannonian basin during more than 60 years of exploitation (1941-2003). Based on their cumulative production, number of reservoirs, average porosity and permeability, obtained recovery and depositional characteristics of reservoir rocks, the Croatian hydrocarbon fields may be divided into three groups (oil), or four groups (gas) (Table 1, 2). In the period 1941-1990 the production started in 38 fields, 13 of which before 1959. The peak was reached in 1980-1989 period, when exploitation started in 12 new fields. However, estimations of economic exploitation are optimistic. The longest period is assumed for the 1st group of fields – approx. 55 years, while for 2nd and 3rd group 46 and 36 years of exploitation are expected, respectively. Moreover, in the 1st group the average number of reservoirs is 16 and lithological composition is very favourable, since reservoirs are represented by sandstones of Pannonian and Pontian age. The exception is the Beničanci field with a reservoir in Lower and Middle Miocene breccias. The prognosed exploitation period of gas fields (without fields in the Adriatic off-shore) is between 5 and 23 years. Relatively homogeneous sandstone lithology, including good regional seals like marls, enables increasing of recovery using fluid injection. Also, injection of CO_2 is planed in favourable reservoirs (immiscible phases, pressure supported) and two pilot projects are either finished (Šandrovac field in 2001) or planned in near future (Ivanić field in 2008). The water-flooding will probably be dominant secondary method for increasing recovery in the future, especially due to the fact that for the CO_2 injection gas transport and careful analysis of fluids interactions in sub-surfaces are necessary. Both approaches can be very easily and successfully applied today due to very good regional tectonic, stratigraphic, depositional and geochemical investigations of the Sava and Drava depressions. It is assumed that over 2-4 times more oil was generated than oil discovered up to now. It means that, at least based on presented statistics, probably some larger fields can be discovered especially in the Drava and Sava depressions.

Keywords: exploitation period, hydrocarbons, Pannonian basin, Croatia.

INTRODUCTION

There are four larger geotectonical units of Neogene age (also called depressions) described in the Croatian part of the Pannonian basin system. These are the Mura, Drava, Sava and Slavonija-Srijem depressions (**Figure 1**). The borders between depressions are generally located along several mountains and massifs in the Northern Croatia or their subsurface extensions that can be recognised as uplifted structures or buried hills covered by Quaternary sediments (**ref. [1], [2]**).

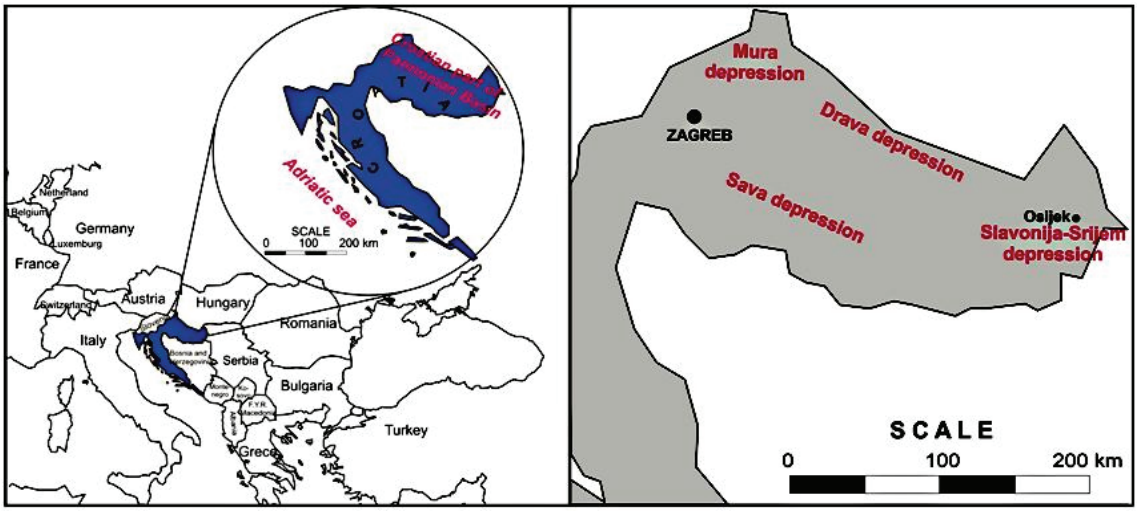

Figure 1: Croatia and its Croatian geotectonical regions

In the last 50 years of hydrocarbon exploration and production in Croatia (led by INA company in the Pannonian and Adriatic areas), 40 oil and 25 gas fields had been discovered and exploited. The total (geological) reserves are 450×10^6 m^3 of equivalent oil. Up to the year 2003 a total of 156×10^6 m^3 of equivalent oil had been recovered from 52 Croatian fields. More precisely, it was 110×10^6 m^3 of oil and over 46×10^9 m^3 of natural gas (**ref. [3]**). Field engineering and reservoir development department of INA takes care of 62 fields in Croatia. Today 15 of them are not in production or are abandoned. The oldest fields are Gojlo, Sumecani, Bunjani, Klostar and Dugo Selo (production started between 1941 and 1957). The youngest fields are Deletovci and Privlaka (1984), Bizovac and Leticani (1989) and Galovac-Pavljani (1991).

RECOVERING METHODS AND RATES

The quantities of recovered fluids in period 1946-2005 are shown in **Figures 2 and 3** by histograms. The cause for a rapid decrease of production after 1989 is three-fold – exhaustion of older fields, Serbian occupation in the Eastern Slavonia 1991-1995 and substantial decrease in exploration activities resulting in no discoveries of new reserves.

The maximal annual production of oil reached 3.14×10^6 tons, which had been kept in periods 1979-1982 and 1985-1988. The gas production reached the maximum in the period 1987-1990 (more than 2×10^9 m^3). It was followed by another smaller maximum (e.g. 2.05×10^9 m^3 in 1993).

According to the production data from the seventies, recovery reached by primary methods for soluble gas regime was 16-20%, gas cap 20-25%, and water injection regime 30-50%. Up to 1970, the average recovery was 25%, with the lowest values

obtained in the largest oil fields Ivanic and Zutica (16%). But, some other large fields reached very high recovery like Benicanci (51%), Stružec (39%) and Klostar (31%). These rates can be compared by recoveries in the same or similar reservoirs in the world.

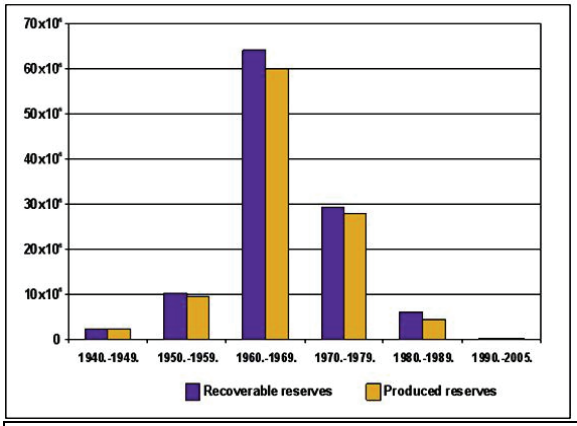

Figure 2: Relation between produced and recoverable oil reserves in relation to the time period of the discovery of the oil field. Graph ordinate represents amount of reserves in m^3

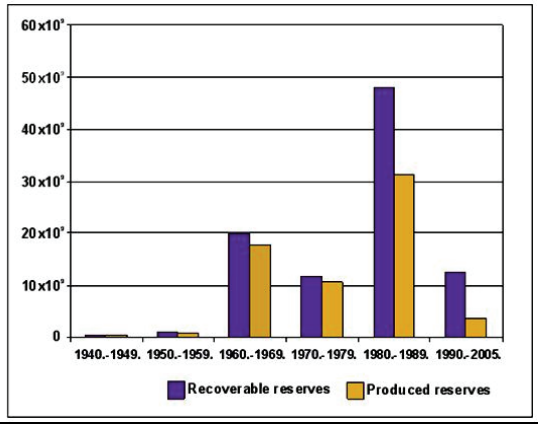

Figure 3: Relation between produced and recoverable gas reserves in relation to the time period of the discovery of the gas field. Graph ordinate represents amount of reserves in m^3

Secondary recovery methods are used to increase the production. The most appropriate and economical method is water injection that is applied at many Croatian fields. It means that half of present day Croatian production originates from water flooded reservoirs. Relation among applied recovery methods is shown in **Figure 4**. Oil recovery in water flooding reservoirs varies between 40 and 54%. Such high values are reached due to favourable oil viscosities. In the last twenty years reservoir pressure was supported by gas injection in oil reservoirs (including original gas cap). This method resulted in additional $16x10^6$ oil tons recovered to the end of 1987. Also, recovery can be increased using horizontal wells (drilled at Zutica, Stevkovica and Bizovac fields) as well as fracturing of rocks characterised by weak petrophysical properties.

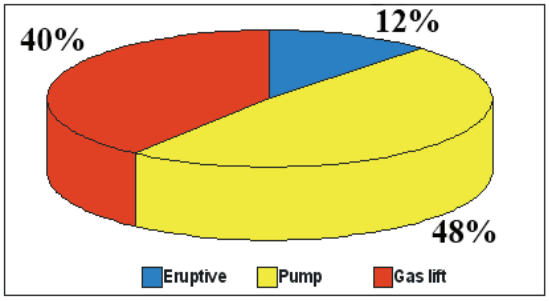

Figure 4: Applied recovery methods in 2004

It is confirmed, based on very detailed exploration, that some reservoirs characterised by intergranular porosity are favourable for application of tertiary recovery methods (*tertiary* means that these methods are applied if primary and secondary methods did not obtain satisfactory recovery). Tertiary methods are also called *unconventional*, *improved methods for recovering from oil reservoirs* or *methods for increasing of*

recovery. Usual terms are Enhanced oil Recovery (EOR) or Improved oil Recovery (IOR).

In the INA laboratories, application of CO_2 injection had been tested for samples collected at 14 Croatian fields (Benicanci, Bunjani, Ivanic, Jagnjedovac, Klostar, Kozarica, Lepavina, Mramor Brdo, Obod, Obod–Lacici, Struzec, Šandrovac, Stevkovica and Zutica). These testing, which had been performed in the last 20 years, resulted in many new engineering data (**ref. [4]**). The method had been found to be well applicable in 33% fields in the condition of complete fluid miscibility, in 59% fields when fluids are partially miscible and in 8% fields when fluids are immiscible. The total bypassed oil in analyzed water flooded reservoirs at mentioned 14 fields is about $140x10^6$ m^3. It means that well-applied tertiary methods can yield another $9\text{-}24x10^6$ m^3 of liquid hydrocarbons.

It can be interesting to analyse the dynamics of production starting, in the 1941-2005 period (**Figures 5 and 6**), when all 38 fields had been activated. The production at the 13 fields was started up to 1959 (34%). The number of new fields was rapidly increased in seventies (29%) with maximum reached between 1980 and 1989 with twelve discovered fields (32%). It was followed by only two new fields found after 1989 (5%). Generally 30 years (1959-1989) can be described as very successful exploration period, because this period had been characterised by many undiscovered structures in Croatian depressions. Such structures (structural and combined traps) could be observed by different (easy applied) methods like gravimetric measurements or surface geomorphological explorations. Almost all older fields had been discovered by the first exploration well. Moreover, improved seismic survey methods, especially including enough resolution for scanning deeper parts of subsurface, played the critical role in discovering of the largest Croatian gas-condensate reservoirs in the Drava depression.

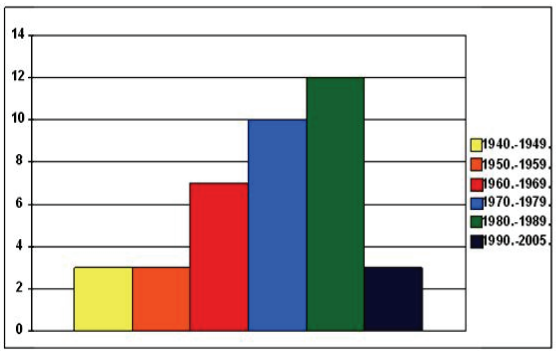

Figure 5: Number of the discovered oil fields during the particular time periods

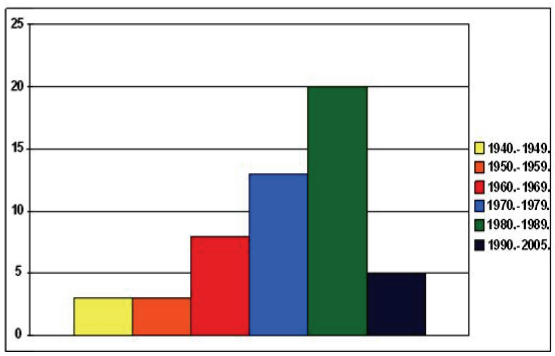

Figure 6: Number of the discovered gas fields during the particular time periods

BASIC RESERVOIR CHARACTERISTICS

In the entire hydrocarbon exploration and production in Croatia almost 3300 wells had been drilled (35% production, 21% measuring wells, 37% abandoned, 5% water injection and 2% others; **Figure 7**).

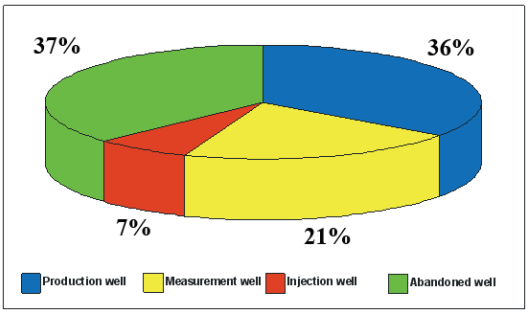

Figure 7: Different type of wells in 2005

Different quantities of hydrocarbons are produced from various types of reservoirs in the sixty-year long production period in Croatia. This production, or reservoirs, can be grouped using some statistical data like average number of reservoirs in the field, average porosity, permeability and recovery data and some other parameters. All fields and reservoirs are selected in the three groups (**Table 1**). Selection is based on data from 37 fields (4 of them are today inactive). Majority of fields are located in the Sava (17) and Drava (15) depressions. The rest are located in the Slavonija-Srijem (3) and Mura depression (2).

Table 1: Oil field groups based on petrophysical properties, production and fluid properties

Basic characteristics	**1st group of fields / reservoirs**	**2nd group of fields / reservoirs**	**3rd group of fields / reservoirs**
Portion of total production (%)	84.8	12.3	2.9
Number of fields	8	11	18
Absolute depths to reservoir tops (m)	-570 to -1700	-310 to -2280	-790 to -2350
Average number of reservoirs	16	9	4
Prognosis of exploitation (years)	55	46	36
Average porosity (%)	21.08	15.62	12.65
Average permeability (10^{-3} μm^2)	3.73-384.00	8.16-196.60	2.9-92.3
Average recovery (%)	33.87	24.73	14.27
Average oil density (kg/m^3)	847.6	873.6	869.5

The first group (8 fields) gave 84.8% of oil production, the second group (11 fields) 12.3%, and the third group (18 fields) only 2.9%. The prognosis for the economically positive production are optimistic, mostly due to fact that the longest production period (approx. 55 years) is assumed for the 1st group (the group characterised by the best parameters). The predicted period for the 2nd group is 46, and for the 3rd group 36 years. The fields characterized by extremely long production period are the Mramor Brdo (80

years), Okoli (74 years) and Stružec (72 years). Here are observed some regularities (trends) that indicated why some of the fields (groups) are more productive than others. The number of reservoirs is decreased in the fields characterized by lower production. The average number of reservoirs in the 1st group is 16, in the 2nd 9 and in the 3rd 4 reservoirs. Depth interval of reservoir tops gradually is increased: in the 1st group top varies between -570 (Sandrovac) and -1700 meters (Benicanci). In the 2nd group top varies between -310 m (Jagnjedovac) and -2280 m (Obod-Lacici). In the 3rd group top is between -790 (Kozarica) and -2350 m (Crnac).

Regarding lithologic composition and reservoir ages in the 1st group there is domination of sandstones of Pannonian and Pontian age. The exception is Benicanci field where reservoir is represented by dolomitic and limestone breccia of Lower- and Middle Miocene ages. The 2nd and 3rd groups include reservoirs of very heterogeneous lithologic composition and ages. For example, the reservoirs in the Stevkovica field consist of effusives, sandstones, breccia and conglomerates of Karpatian and Badenian ages. In the Deletovci field, reservoir rocks are represented by granites, gneisses, schists and diabases of Palaeozoic (?) age as well as conglomerates, breccia and sandstones of Badenian age. There are also confirmed reservoirs of Triassic age (dolomitic breccia in the Kucanci-Kapelna), Cretaceous age (carbonates in the Obod-Lacici) and Oligo-Miocene age (conglomerates and sandstones in Sumecani and Bunjani). According to the available knowledge it can be assumed that in the Croatian fields, oil reservoirs in sediments younger than Lower Pontian can not be found.

Lithologic composition and reservoir age as well as their depth are in direct correlation with changes of petrophysical properties and obtained recoveries (**ref. [1], [2], [5], [6]**). Average porositiy is decreased from 21.08% in the 1st group to 15.62% in the 2nd group, i.e. to 12.65% in the 3rd group. The permeability in reservoirs is 3.37-384x10^{-3}μm^2 (1st group), 8.16-196.6x10^{-3}μm^2 (2nd group) and 2.9-92.30x10^{-3}μm^2. It is obvious that petrophysical properties decrease from the 1st group to the 3rd group, as well as recovery rates (34%, 25% and 14% retrospectively; **Table 1**).

The **gas** fields are classified according to the achieved production in 4 groups (**Table 2**). The limit values for group are (1) more than 1x10^9 m^3, (2) >100x10^6 m^3, (3) more than 10x10^6 m^3 and (4) less than 10x10^6 m^3. The majority of fields are located in the Drava depression, then in Sava depression etc. Structural traps dominate. These are different anticlines and horsts. Stratigraphic traps are rare, but can be very important for some reservoirs, especially buried hills. The age of reservoirs is not always clearly defined, but in the 10 fields reservoirs they are older than Neogene (Palaeozoic and Mesozoic magmatic, metamorphic and sedimentary rocks), in 22 fields the age is Lower and Middle Miocene and in 20 fields it is Upper Miocene. There is no regularity of reservoir ages in the 4 groups. Predicted period of production (without gas fields in Adriatic sea) varies between 5 and 23 years. The largest fields could be the most active fields in production (similar like oil fields). Other parameters listed in **Table 2** are characterised by similar trends observed for oil fields (**Table 1**).

Table 1: Gas fields in groups based on petrophysical properties, production and fluid properties

Basic characteristics	1st group of fields / reservoirs	2nd group of fields / reservoirs	3rd group of fields / reservoirs	4th group of fields/ reservoirs
Portion of total production (%)	90.75	7.83	1.38	0.04
Number of fields	13	16	18	5
Absolute depths to reservoir tops (m)	-150 do -3054	-240 do -3400	-240 do -2230	-350 do -2110
Average number of reservoirs	13	6	5	5
Average porosity (%)	16.6-25.2	16.4-22.0	14.3-18.2	12.3-15.6
Average permeability (10^{-3}	5.869-184.70	4.96-30.51	30.2-151.82	2.85-13.25
Average recovery (%)	33.87	24.73	14.27	
Average gas density compared by air	0.672	0.705	0.678	-

CONCLUSION

Some of the new studies revealed that in the Croatian part of Pannonian basin, 2-4 times more oil had been generated than it was proven in existing reservoirs (**Figure 8**). It means that there are for certain some subtle large reservoirs, what is also statistically proven and presented in **Tables 1 and 2**, that could be discovered especially in the Drava and Sava depressions.

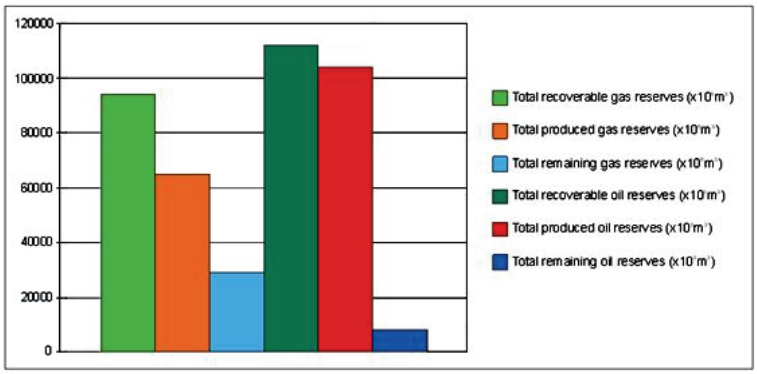

Figure 8: Overview of the total Croatian hydrocarbon reserves. Gas reserves are presented in millions while oil reserves are presented in thousands of cubic meters.

Such reservoirs can be discovered using different geological models (depositional, geochemical, tectonical, and modelling of petroleum systems) that could be base for further explorations. The remaining reservoir potential can be expected in the basement of Tertiary system, maybe more along depression margins, but also at other locations characterised by uplifted palaeorelief (buried hills). Also, the stratigraphic traps within the Pannonian and Pontian sediments (so called subtle traps) can now be effectively observed by 3D seismic.

But, higher interests of explorers needs to be directed to sediments of Lower and Middle Miocene that are consist of different lithofacies. These formations can be very favourable for discovering stratigraphic traps, but probably characterised by poorer reservoir properties than stratigraphic traps assumed in Upper Miocene deposits.

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